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Correlators and back-ends

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CSIRO

Outline

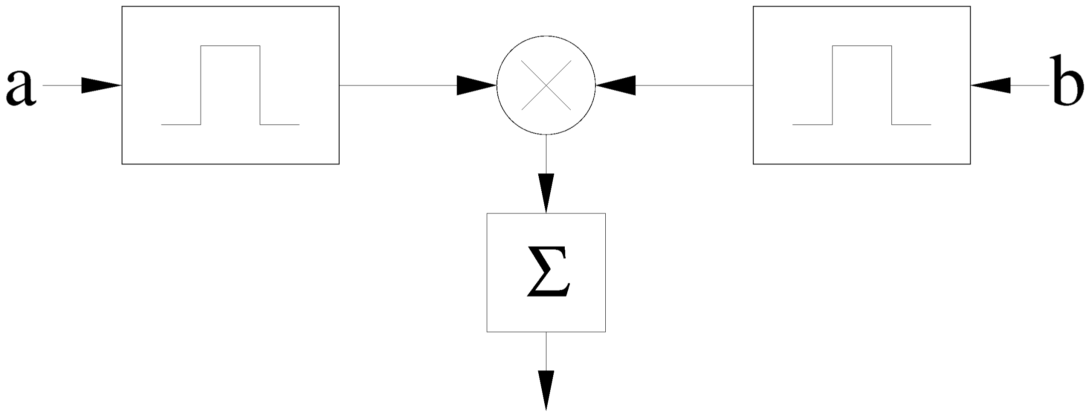
- What is a correlator and why do we need one?
- The basics: Filterbanks, FX and XF.
- The number of bits
- ATCA, ASKAP, Parkes, Mopra back-ends
- Some other correlators
- Final thoughts

Radio astronomy is cool!

Reality

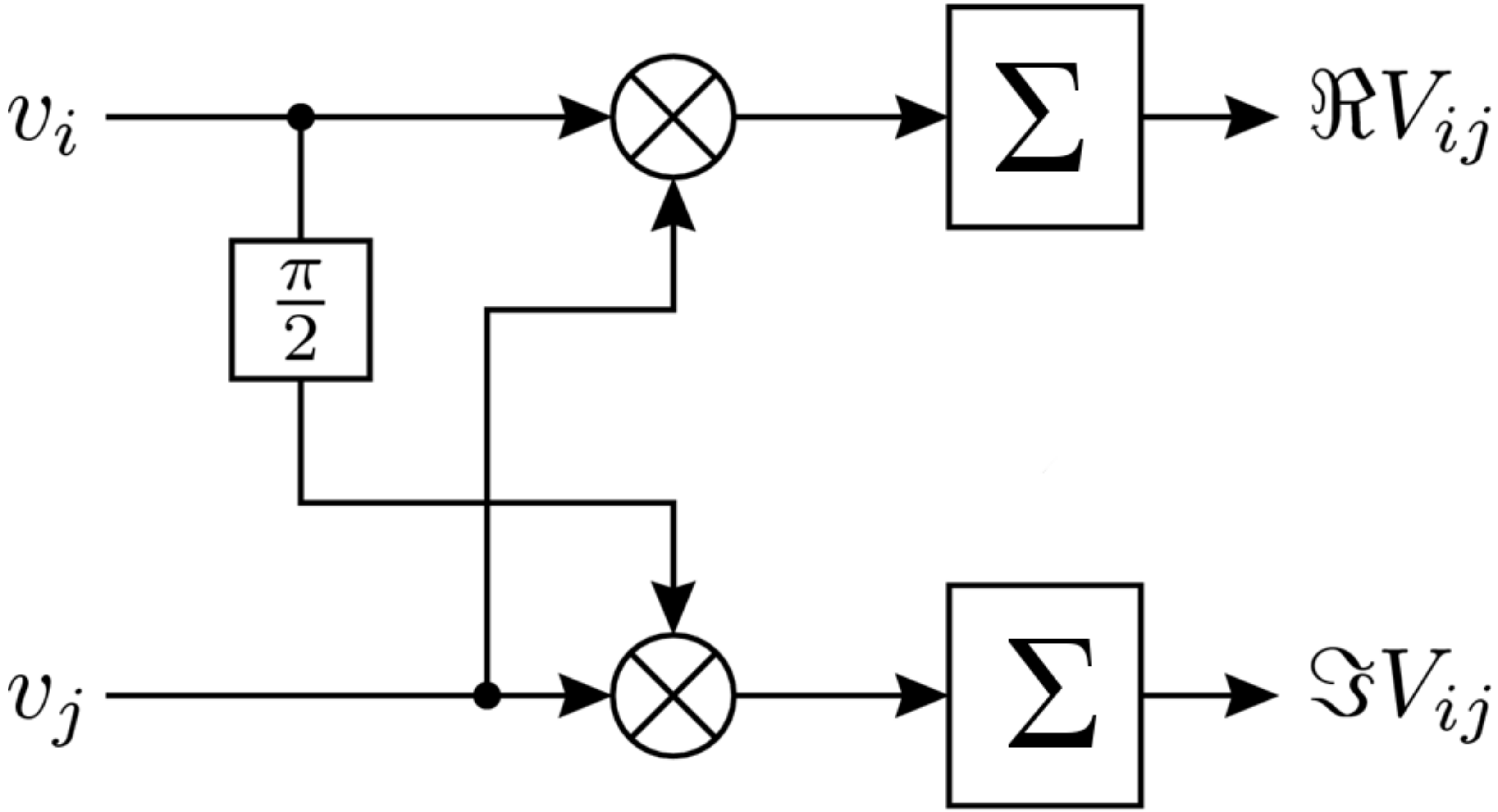
- The signal to noise ratio is (usually) pitifully small.
  - Perhaps 1/500, perhaps several orders of magnitude poorer!
- The “signal” is a sort of noise.
  - No modulation and little structure.
- To detect a astronomical source
  - Look for changes in noise power with position and/or frequency (single dish), or
  - Look for correlations of the noise between different antennas (interferometry).

Basic correlator cell



- Power measurement – auto-correlator (*a* and *b* the same signal).
- Cross correlator (*a* and *b* different signals).

Complex correlator cell



Spectral resolution

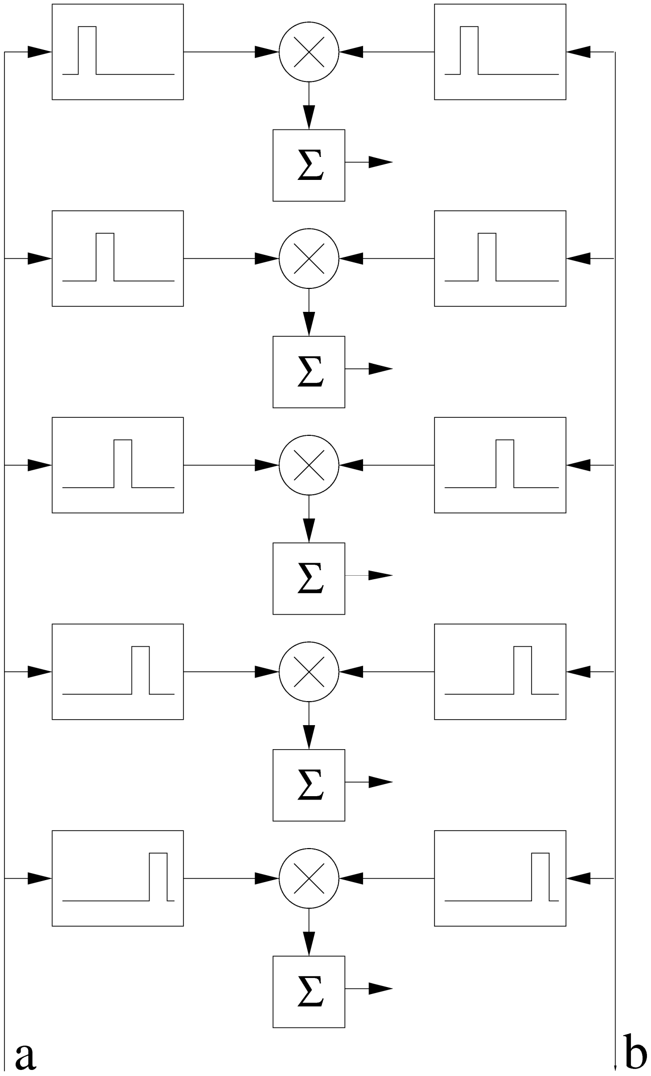
Modern correlators decompose the signals into multiple spectral channels.

- A basic requirement for spectral observations
- Desirable for wideband continuum experiments to avoid some wideband issues.

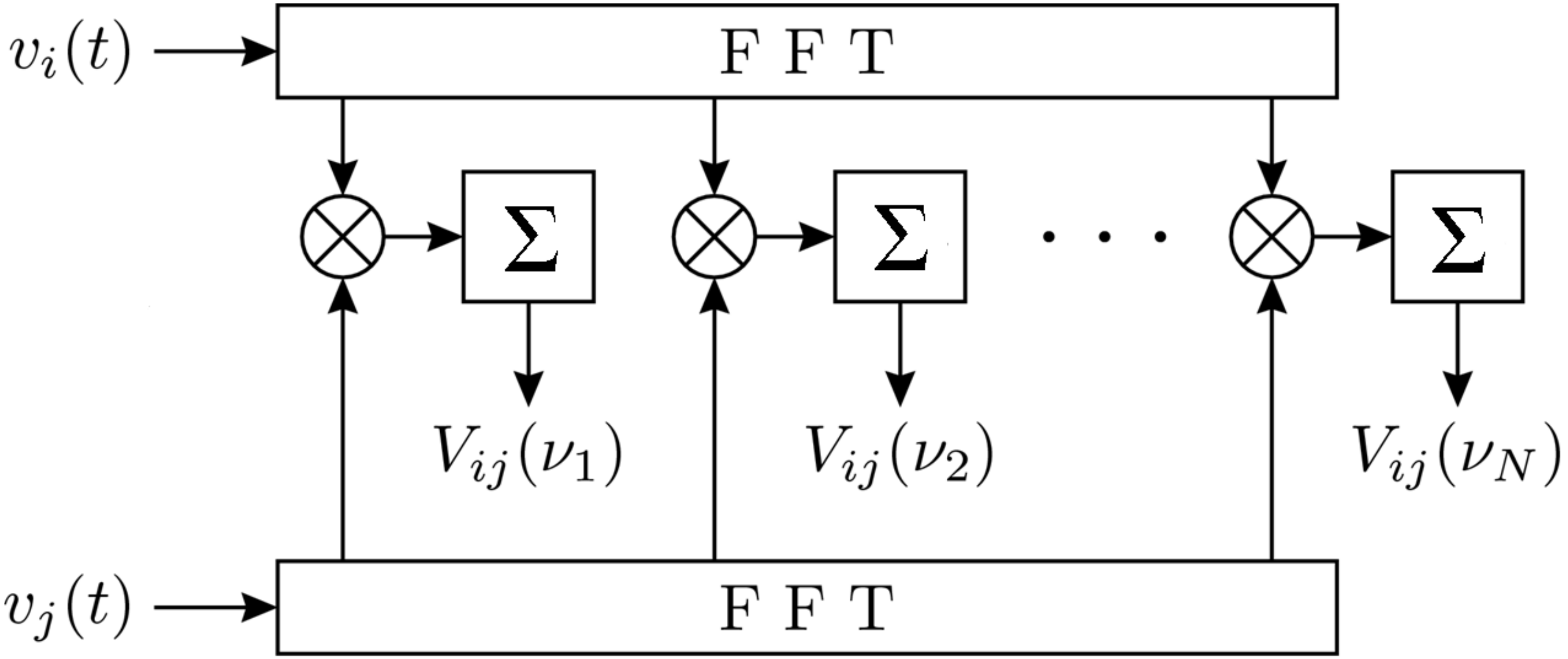
Different astrophysics will require different requirements for spectral resolution and total bandwidth

Modern correlators have "huge flexibility".

A filterbank correlator



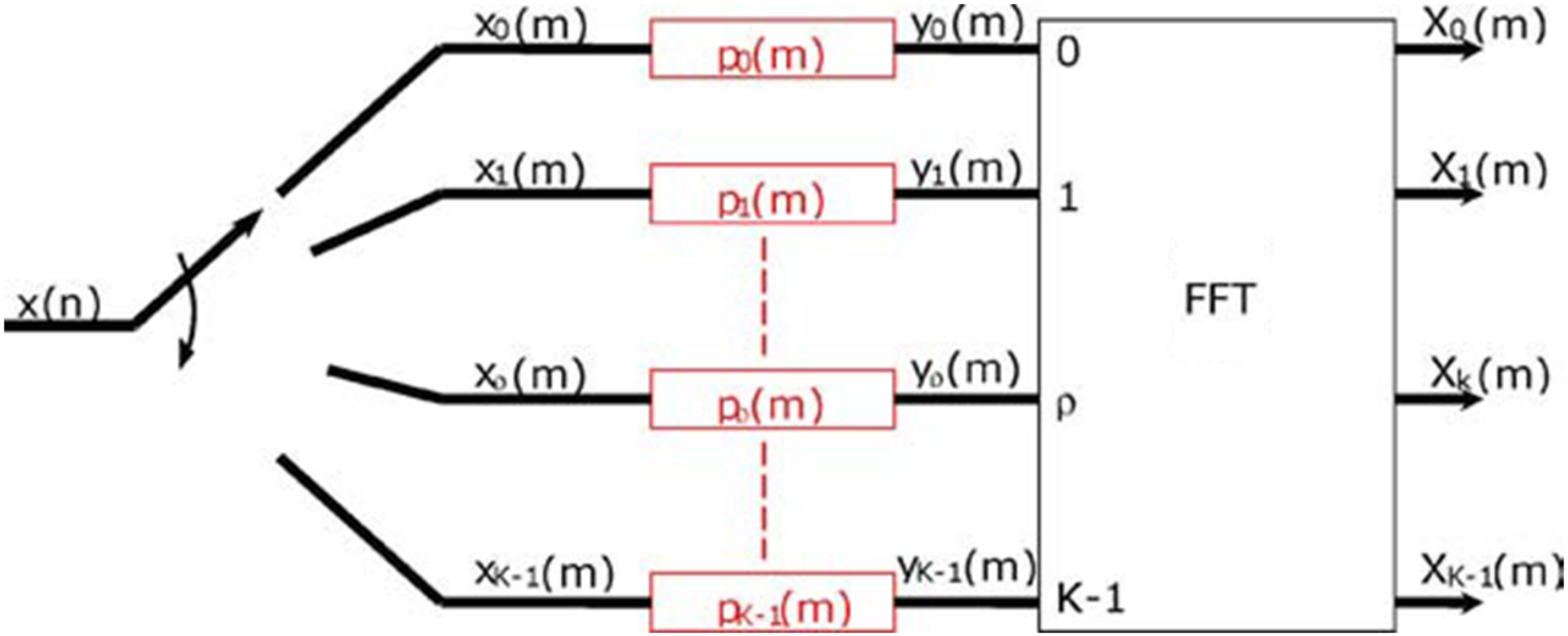
Digital "FX" correlator



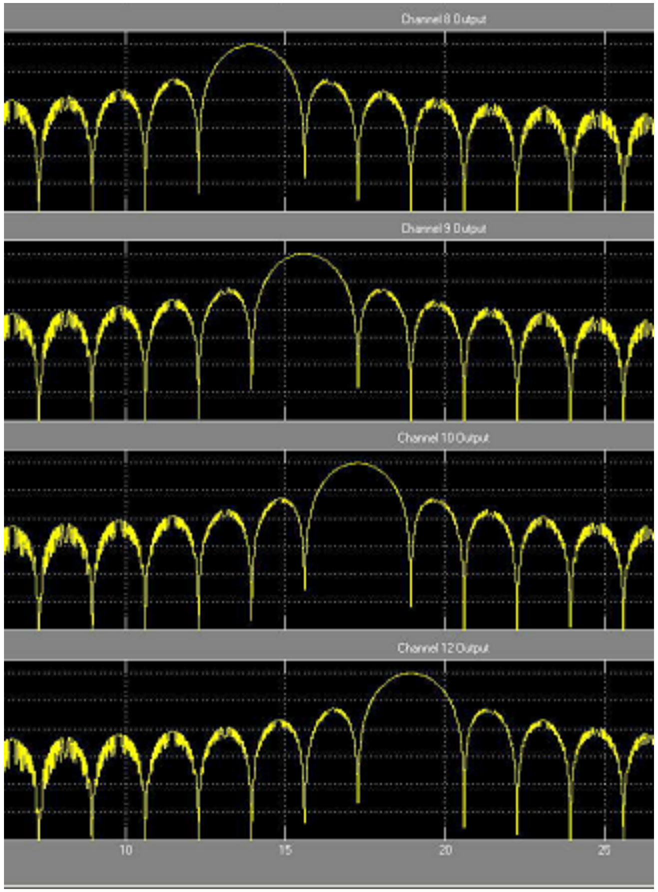
FX correlators

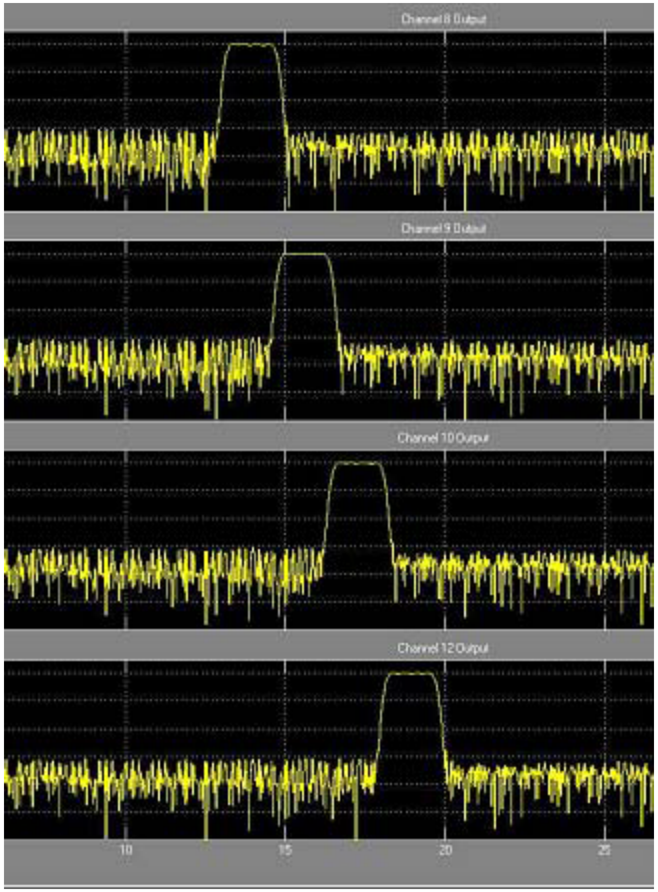
- A simple digital filterbank can be formed by a simple Fourier transform (FFT)
- FX correlators can use more sophisticated digital filterbanks. eg polyphase filterbanks

Polyphase filterbank

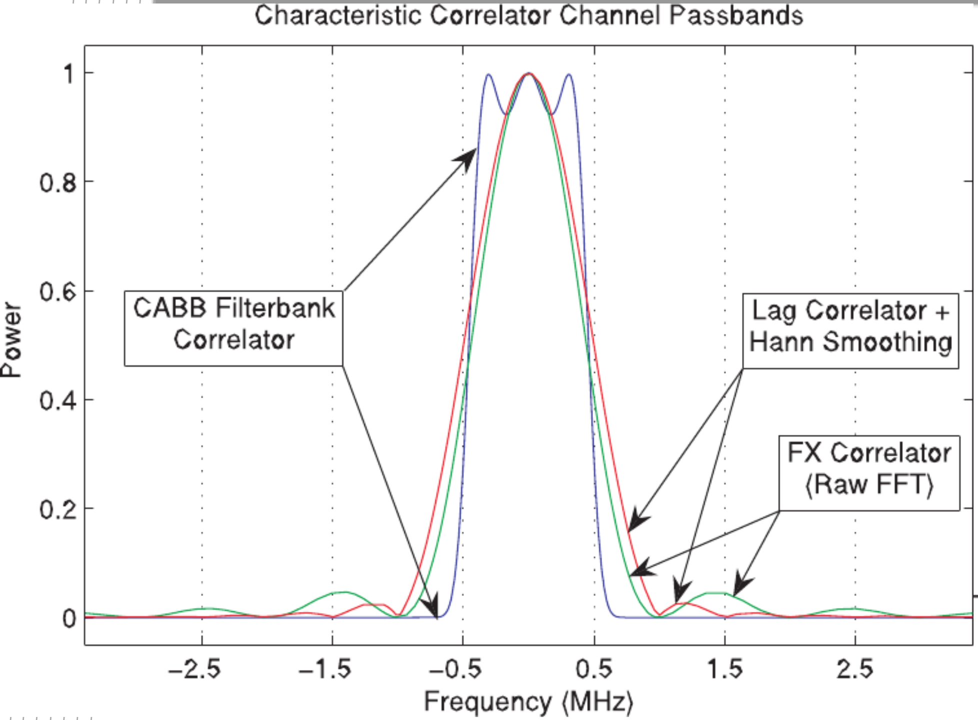


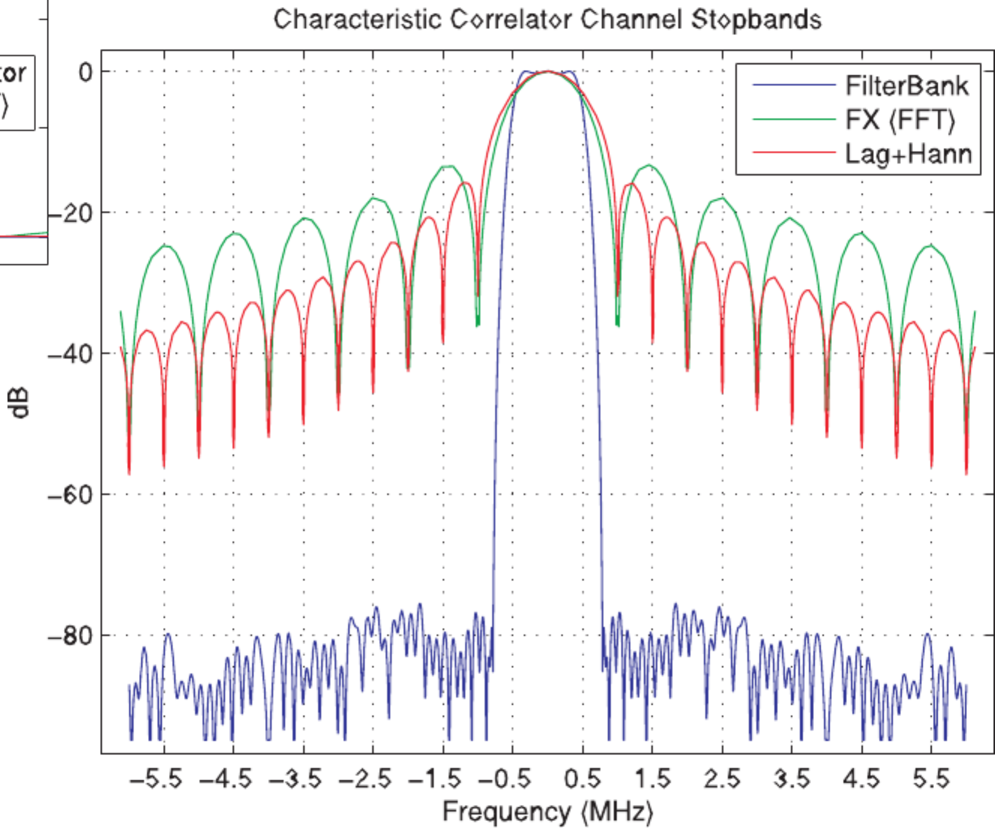
Why polyphase filterbanks?



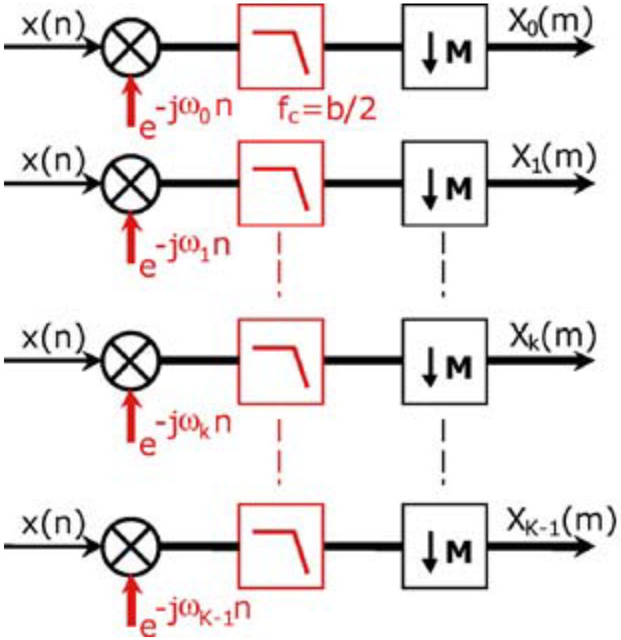


Why polyphase filterbanks?





How a polyphase filterbank works …



XF (lag) correlators

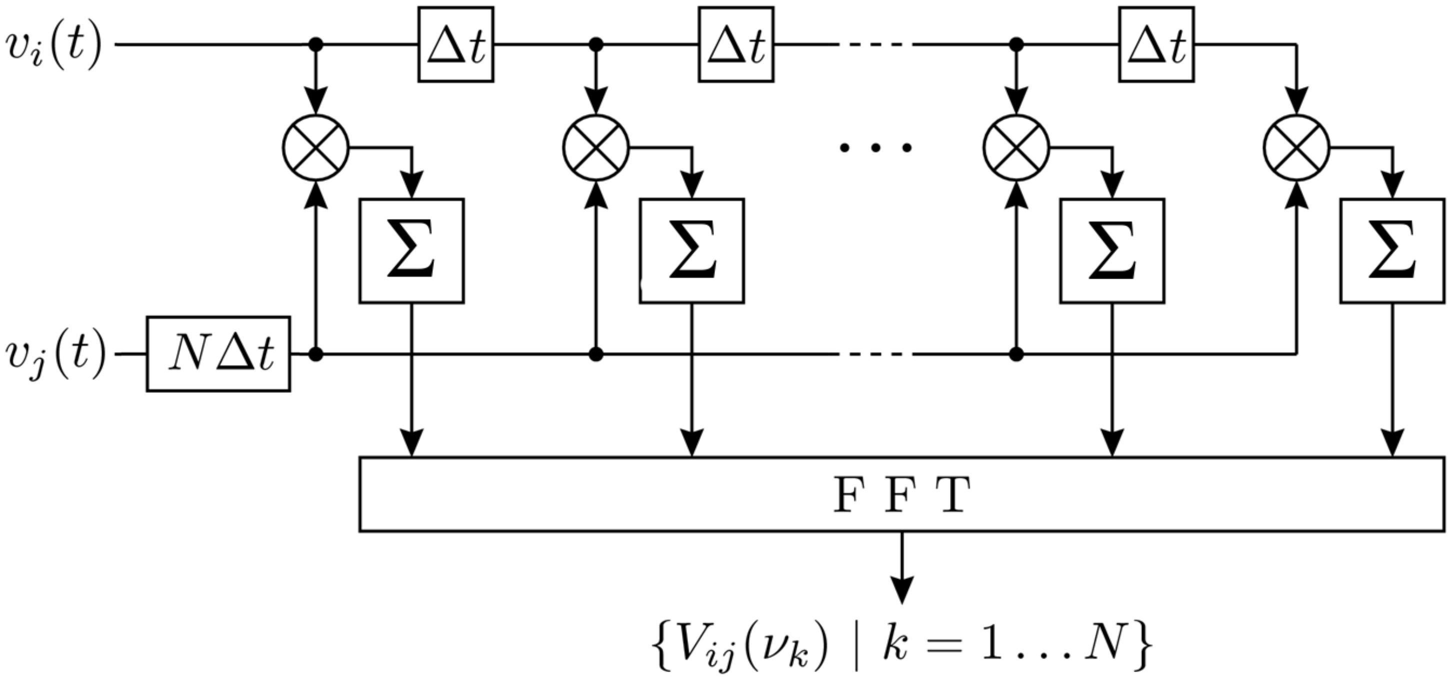
An alternative approach to designing a correlator is to use the identity

$$A(\nu)B^*(\nu) = \mathcal{F}[a(t) \star b(t)]$$

where

$$a(i) \star b(i) = \sum_{n=0}^{N-1} a(i)b(i+n)$$

XF structure



XF or FX?

- FX is more efficient for large number of antennas.
- FX correlators are more readily designed to be robust to RFI.
- XF correlators tend to have more modest data wordsize requirements.
- XF correlators tend to be simpler *(but also less adaptable to more complex requirements)*

Number of bits

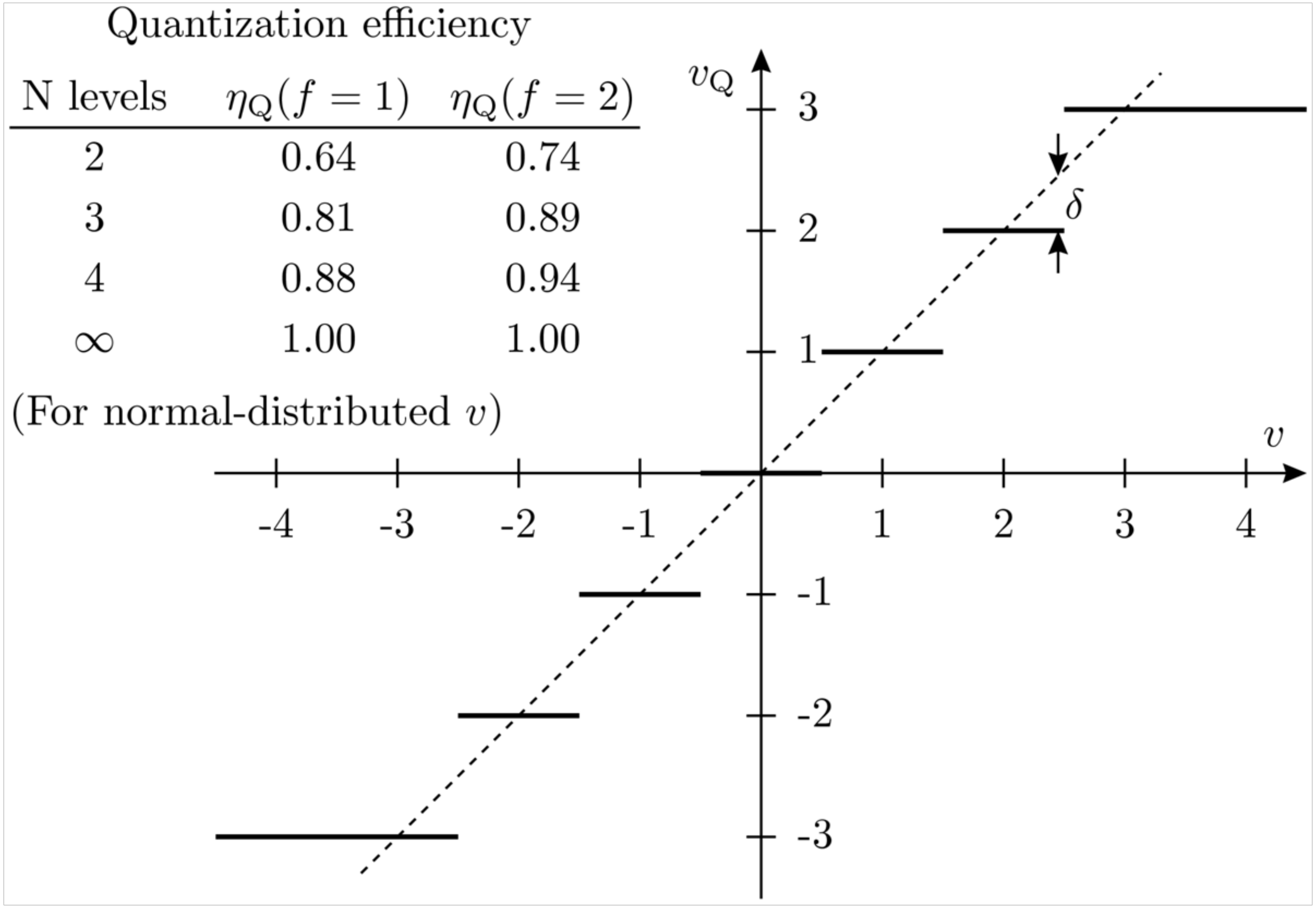
For signals that are broadband Gaussian noise, number of bits can be small.

- Number of bits traditionally small – typically 1, 2 or 3 bits.
- Modern (low frequency) correlators tend to have “many” bits – typically 8 to16 bits.

Number of bits influenced by:

- Correlator “efficiency”
- Robustness to narrowband signals (RFI)

Quantization efficiency

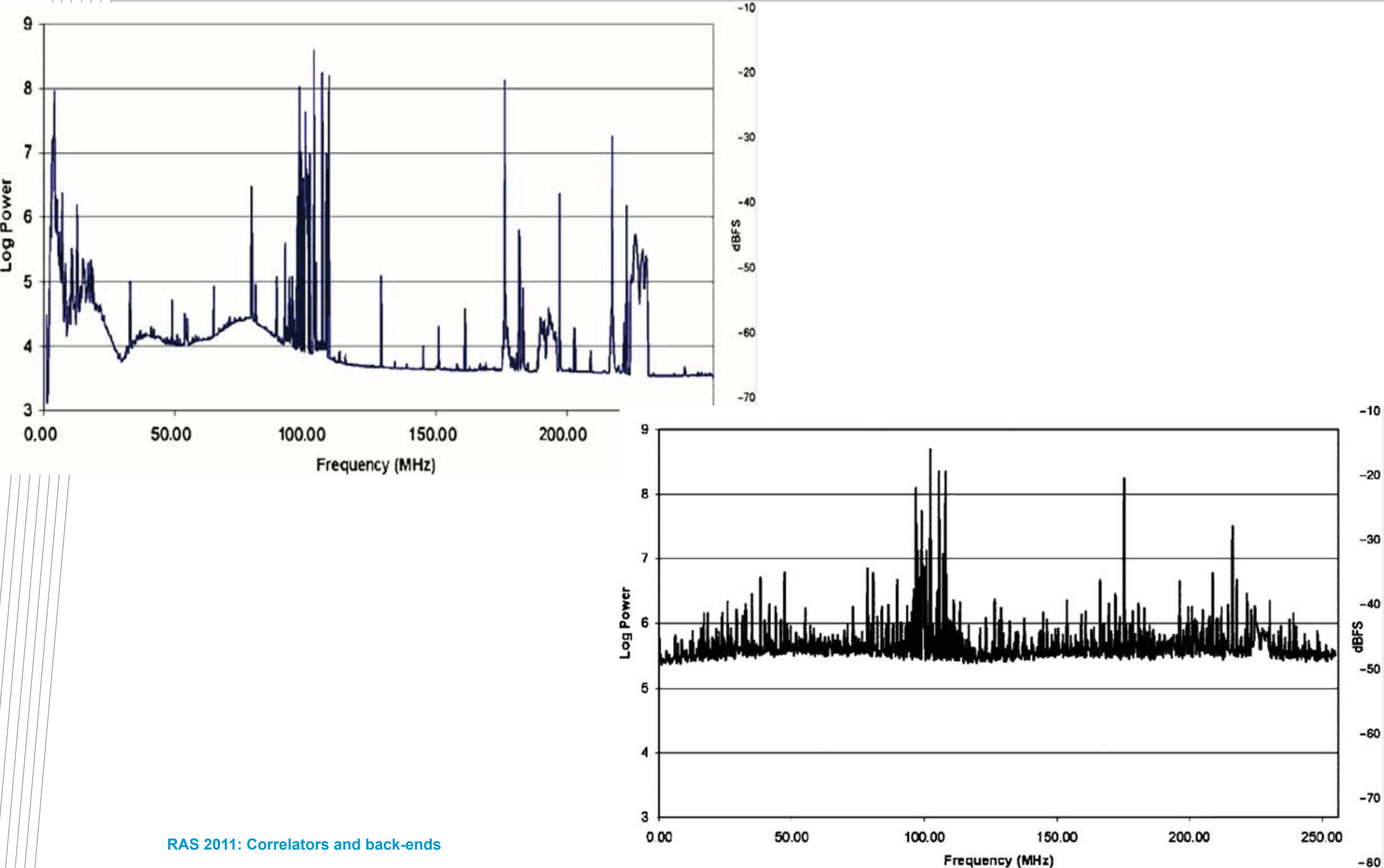


Quantization efficiency

N levels	$\eta_Q(f = 1)$	$\eta_Q(f = 2)$
2	0.64	0.74
3	0.81	0.89
4	0.88	0.94
∞	1.00	1.00

(For normal-distributed v)

How many bits?



CABB

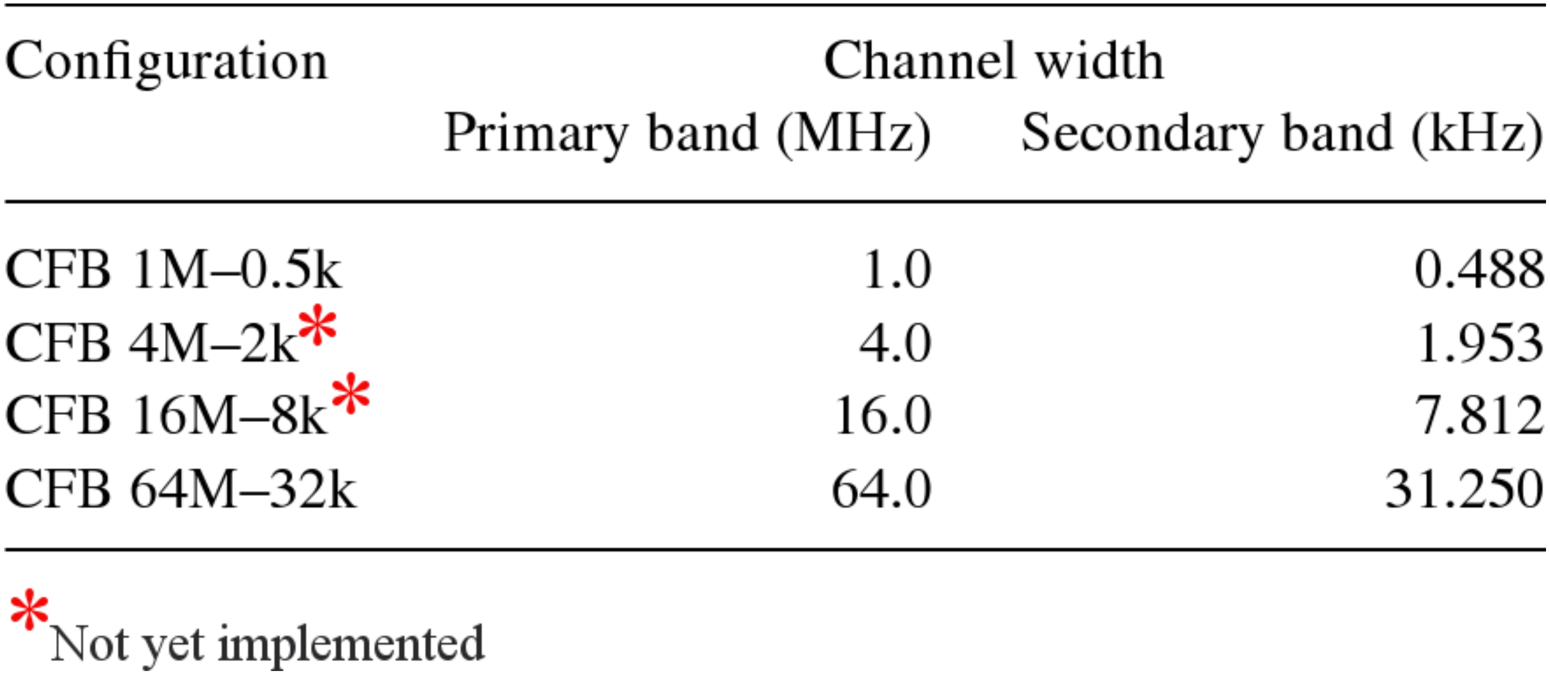
- An FX correlator using a polyphase filterbank
- Input

  2 freq bands, 2 pols, 2 GHz of bandwidth.

- Output per freq band
  - Full Stokes
  - up to 2048 channels at 1 MHz each freq band (“primary channels”)
  - up to 16 “zoom bands” with 2048 channels down to 0.5 kHz resolution using a second stage filter bank (“secondary channels”)
  - Primary and secondary channels produced in parallel.
- Characteristics:

  9 bit input; no internal precision loss; low channel sidelobes; robust to RFI and total power fluctuations.

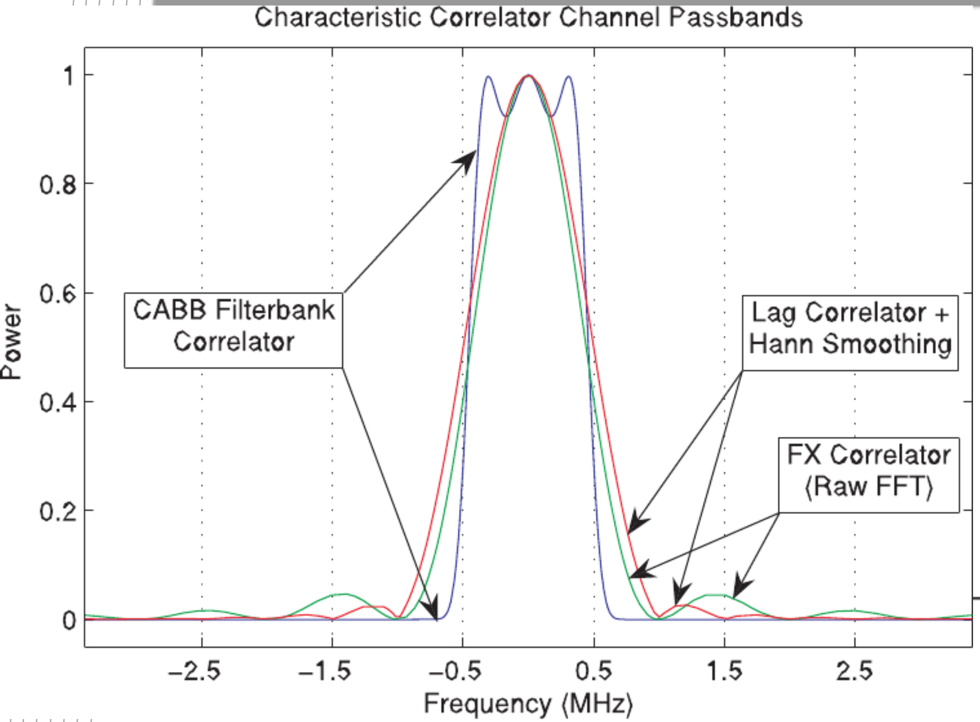
CABB configurations

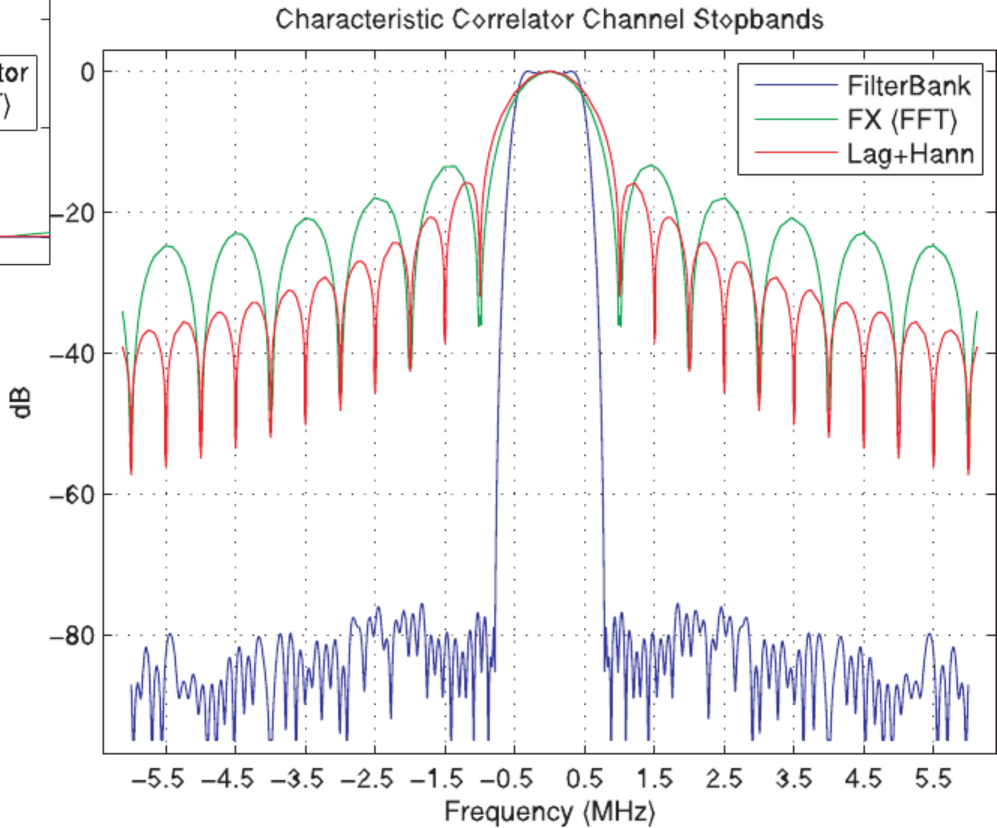


Configuration	Channel width	
	Primary band (MHz)	Secondary band (kHz)
CFB 1M–0.5k	1.0	0.488
CFB 4M–2k*	4.0	1.953
CFB 16M–8k*	16.0	7.812
CFB 64M–32k	64.0	31.250

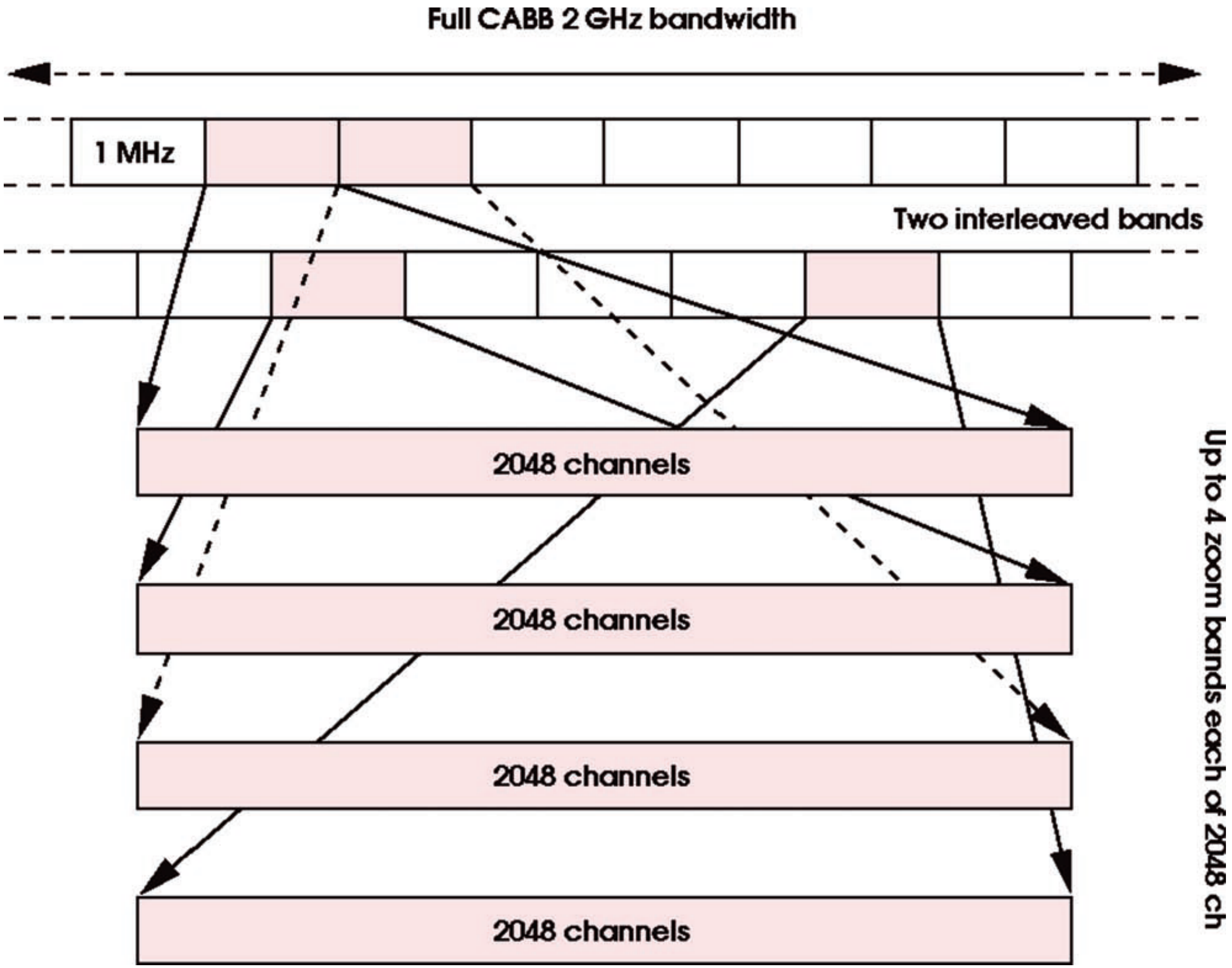
*Not yet implemented

The primary channel bandpasses





CABB Rack

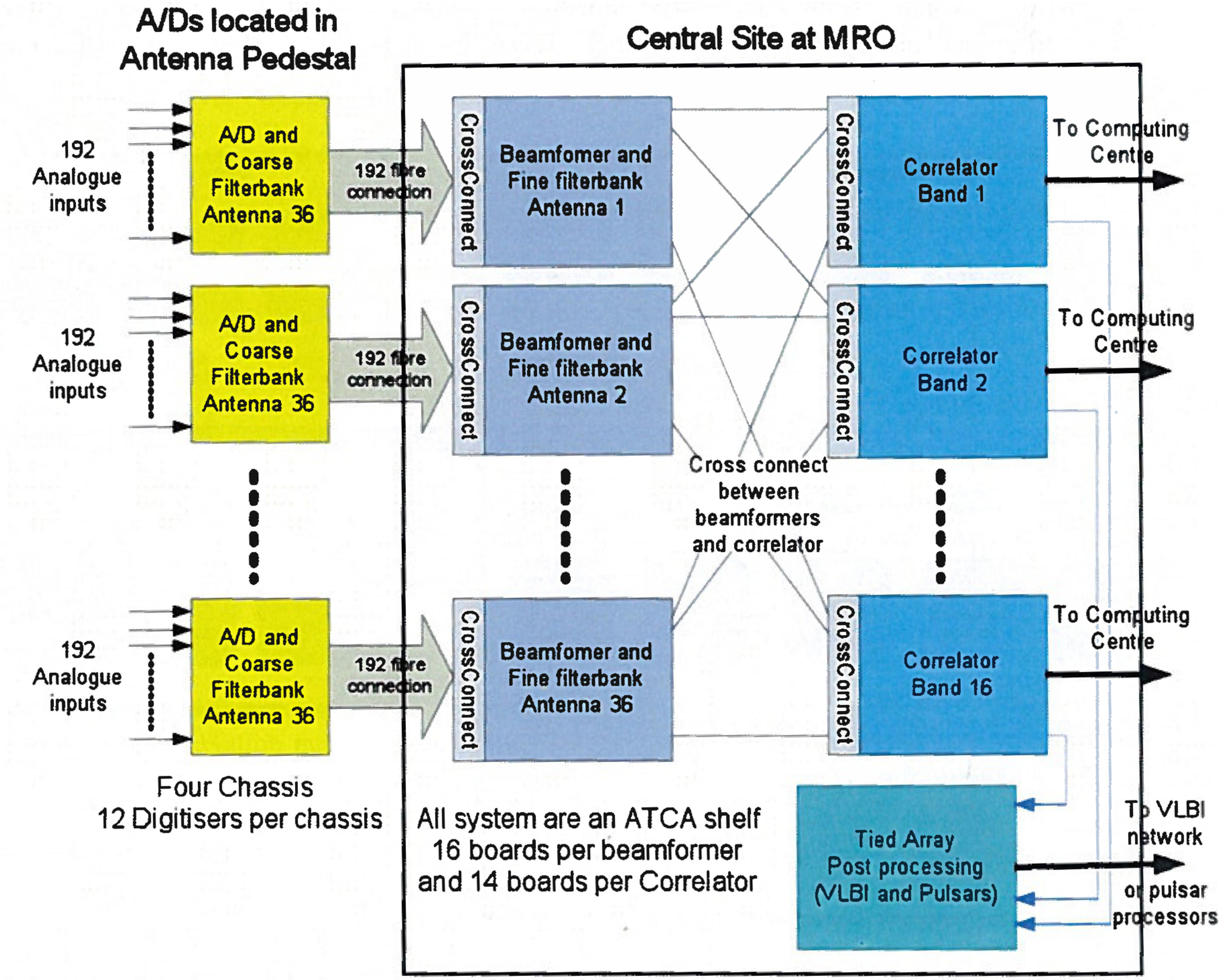

Full CABB 2 GHz bandwidth
1 MHz
Two interleaved bands
2048 channels
2048 channels
2048 channels
2048 channels
Up to 4 zoom bands each of 2048 ch

“Old” AT Correlator

- A XF (lag) correlator with 2-bit words
- Inputs:

  2 freq bands, 2 pols, 128 MHz bandwidth (filters with 64, 32, 16, 8 and 4 MHz bandwidth also possible)
- Outputs:
  - 8 MHz channel bandwidth in 128 MHz mode
  - Down to 2kHz channels in 4 MHz mode
  - Polarizations must be sacrificed for highest spectral resolutions

ASKAP back-end (BETA array)



Four Chassis
12 Digitisers per chassis

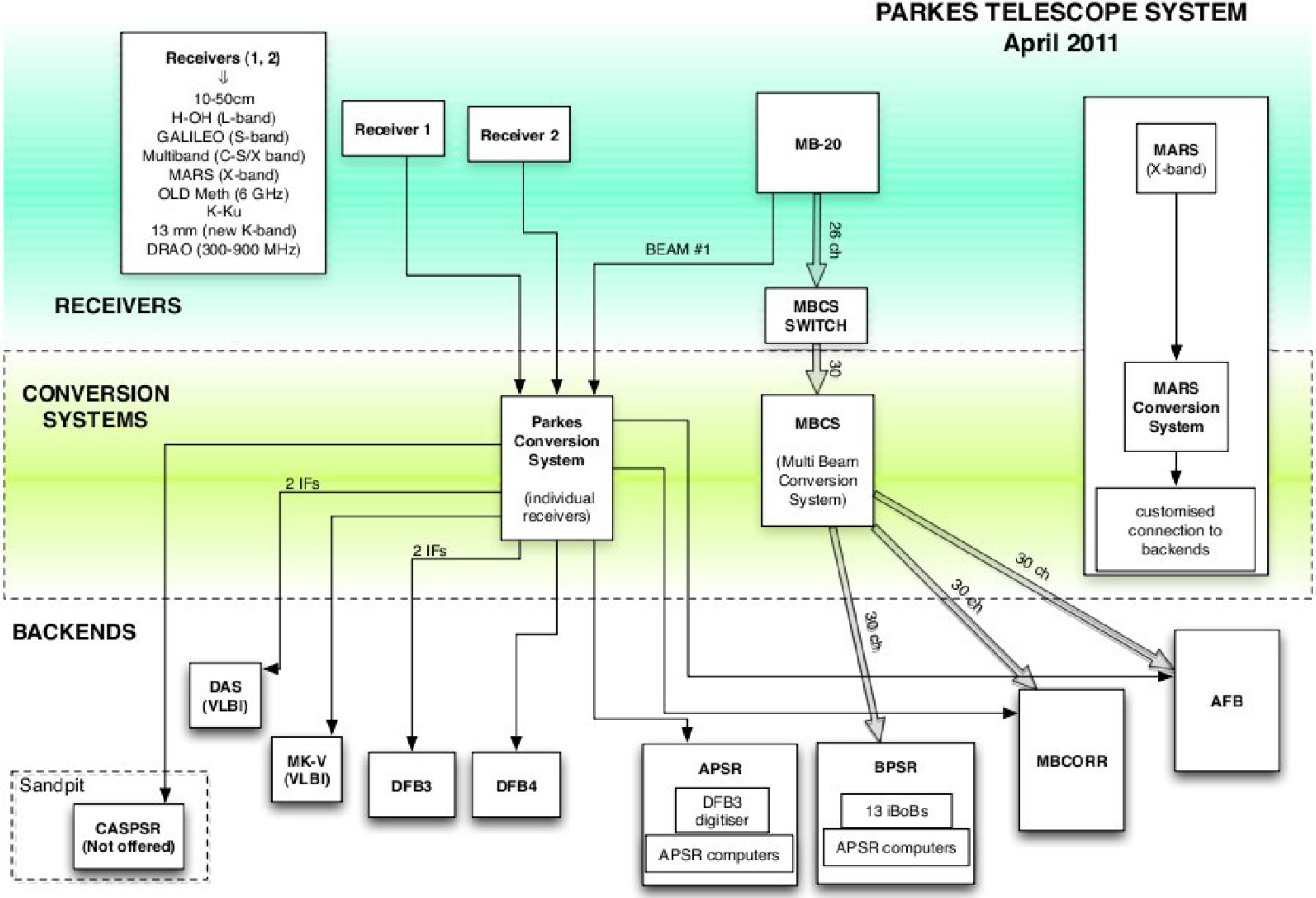
All system are an ATCA shelf
16 boards per beamformer
and 14 boards per Correlator

ASKAP (BETA) details

- An FX correlator with polyphase filterbanks.
- Four stage backend:

  Filterbank; beamformer; filterbank; correlator.
- 12-16 bits internal
- 16416 channels across 304 MHz (not configurable) – 18.5 kHz resolution
- 36 dual pol beams formed from 192 elemental feeds.

Parkes



PARKES TELESCOPE SYSTEM
April 2011

RECEIVERS

Receivers (1, 2)
⇓
10-50cm
H-OH (L-band)
GALILEO (S-band)
Multiband (C-S/X band)
MARS (X-band)
OLD Meth (6 GHz)
K-Ku
13 mm (new K-band)
DRAO (300-900 MHz)

Receiver 1

Receiver 2

MB-20

26 ch

BEAM #1

MBCS SWITCH

30

MARS (X-band)

CONVERSION SYSTEMS

Parkes Conversion System (individual receivers)

MBCS (Multi Beam Conversion System)

MARS Conversion System

customised connection to backends

2 IFs

2 IFs

30 ch

30 ch

30 ch

BACKENDS

DAS (VLBI)

MK-V (VLBI)

DFB3

DFB4

APSR
DFB3 digitiser
APSR computers

BPSR
13 iBoBs
APSR computers

MBCORR

AFB

Sandpit

CASPSR (Not offered)

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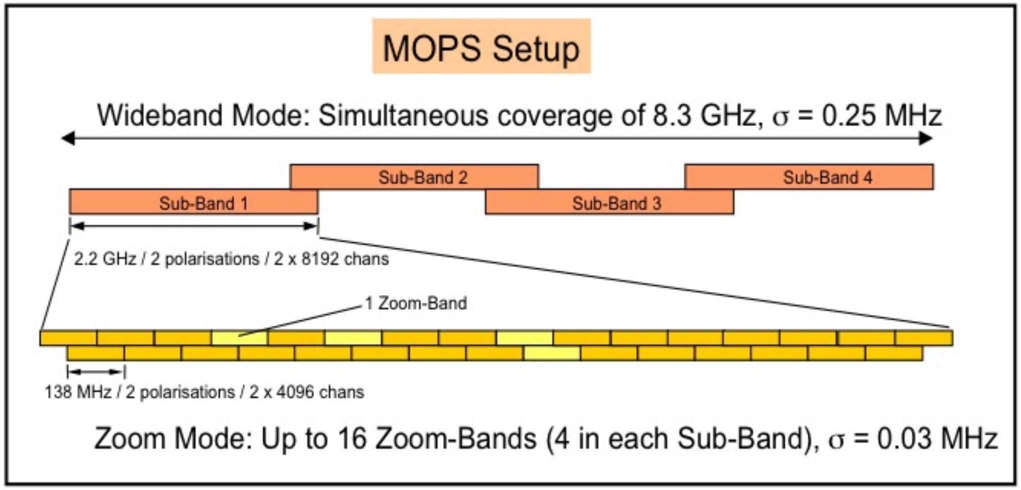
Parkes back-ends

Single dish telescope – so auto-correlation rather than cross correlation is relevant.

- HI multibeam correlator – supports 26 channels (eg dual polarization for 13 beams). XF autocorrelator.
- Methanol multibeam correlator – an augmented version of the HI multibeam.
- DFB3 and DFB4 – based on CABB technology.
- Multiple VLBI and pulsar recorders and backends.

Mopra (MOPS)

- An FX design with polyphase filterbank – a precursor of the CABB design.
- 2-bit digitization
- 4 banks of 2.2 GHz bandwidth, dual pol.
- Each band broken into 4 zoom bands of 137.5 MHz, 4096 channels.



EVLA correlator (WIDAR)

- XF architecture duplicated 64 times
  - Four 2GHz basebands per polarization
  - Polyphase filterbank makes 16 subbands per baseband
  - 16,384 channels/baseline at full sensitivity
  - 4 million channels with less bandwidth!
- 32 stations
- 2 stations at 25% bandwidth or 4 stations at 6.25% bandwidth can replace 1 station input
- 3 to 8 bits (internally sometimes limited)
- VLBI ready
- ***Massive number of different modes and options.***

ALMA

A hybrid XF correlator – 64 antennas.

- 4 freq bands, 2 pol, 2 GHz bandwidth
- 3-bit sampling
- Digital filterbands split each freq band into up to 32 sub-bands.
- Complex trade-offs.

Possible other back-end functions

- Switched power measurement (tracking system gain)
- Delay tracking (usually implemented in two steps: coarse and sub-sample tracking)
- Fringe rotation and Doppler tracking
- Covariance matrix for phase array feeds

- *Beam switching (single dish observations)*
- *Walsh switching demodulation*

Special topics

- Software correlators (e.g. DiFX)
- VLBI correlators
- Correlators and back-ends for pulsars (search and timing).
- High time resolution modes
- Transients
- RFI rejection

ATNF personnel responsible for the design and construction of correlators include: Warwick Wilson, Dick Ferris, Evan Davis, Paul Roberts, John Bunton, Grant Hampson and Alan Ng.

Notable publications

- deBoer et al, 2009, “Australian SKA pathfinder…”, Proc IEEE
- Wilson et al, 2011, “The AT Compact Array broadband backend …”, MNRAS
- ATCA and Parkes observer user guides

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Thank you